UNITED STATES PATENT APPLICATION

FOR

TAILORED SPACER WALL COATINGS
FOR REDUCED SECONDARY ELECTRON EMISSION

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FOR REDUCED SECONDARY ELECTRON EMISSION

TECHNICAL FIELD

The present claimed invention relates to the field of flat panel displays. More

10   specifically, the present claimed invention relates to a spacer assembly for a flat

panel display.

BACKGROUND ART

In some flat panel displays, a backplate is commonly separated from a

15   faceplate using a spacer assembly. In high voltage applications, for example, the

backplate and the faceplate are separated by spacer assemblies having a height of

approximately 1-2 millimeters. For purposes of the present application, high voltage

refers to an anode to cathode potential greater than 1 kilovolt. In one embodiment,

the spacer assembly is comprised of several strips or individual wall structures each

20   having a width of about 50 microns. The strips are arranged in parallel horizontal

rows with each strip extending across the width of the flat panel display. The spacing

of the rows of strips depends upon the strength of the backplate and the faceplate

and the strips. Because of this, it is desirable that the strips be extremely strong.

The spacer assembly must meet a number of intense physical requirements. A

25   detailed description of spacer assemblies is found in commonly-owned co-pending U.S.

Patent Application Serial No. 08/683,789 by Spindt et al. entitled "Spacer Structure

for Flat Panel Display and Method for Operating Same". The Spindt et al. application

was filed July 18, 1996, and is incorporated herein by reference as background material.

In a typical flat panel display, the spacer assembly must comply with a long list of characteristics and properties. More specifically, the spacer assembly must be strong enough to withstand the atmospheric forces which compress the backplate and faceplate towards each other. Additionally, each of the rows of strips in the spacer assembly must be equal in height, so that the rows of strips accurately fit between respective rows of pixels. Furthermore, each of the rows of strips in the spacer assembly must be very flat to insure that the spacer assembly provides uniform support across the interior surfaces of the backplate and the faceplate.

The spacer assembly must also have good stability. More specifically, the spacer assembly should not degrade severely when subjected to electron bombardment. As yet another requirement, a spacer assembly should not significantly contribute to contamination of the vacuum environment of the flat panel display or be susceptible to contamination that may evolve within the tube.

Additionally, it is desirable to have a spacer assembly which provides a secondary electron emission coefficient (SEEC) which stays at a value of approximately 1. SEEC is defined as the number of electrons emitted from a surface per electron incident on the surface. Such a value is commonly not achieved in conventional spacer assemblies, for a variety of reasons. As an example, the variation in energy of electrons impinging the spacer assembly tends to vary across the length (anode to cathode dimension) of the spacer assembly. That is, electrons impinging on the spacer assembly near the cathode have an energy which is typically much less than the energy of electrons which strike the spacer assembly near the

anode. As a result of the variation in energy of impinging electrons, the secondary emission coefficient function of a conventional spacer assembly will also vary significantly from the portion of the spacer assembly near the cathode to the portion of the spacer assembly near the anode.

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Thus, need exists for a spacer assembly which is tailored to provide a secondary electron emission coefficient of approximately 1 for the spacer assembly when the spacer assembly is subjected to flat panel display operating voltages. A further need exists for a spacer assembly which meets the above need and which does

10   not degrade severely when subjected to electron bombardment. Still another need exists for a spacer assembly which does not significantly contribute to contamination of the vacuum environment of the flat panel display or be susceptible to contamination that may evolve within the tube.

DISCLOSURE OF THE INVENTION

The present invention provides a spacer assembly which is tailored to provide a secondary electron emission coefficient of approximately 1 for the spacer assembly when the spacer assembly is subjected to flat panel display operating voltages. The

5   present invention further provides a spacer assembly which accomplishes the above achievement and which does not degrade severely when subjected to electron bombardment. The present invention further provides a spacer assembly which accomplishes both of the above-listed achievements and which does not significantly contribute to contamination of the vacuum environment of the flat panel display or

10 be susceptible to contamination that may evolve within the tube.

In one embodiment, the present invention is comprised of a spacer structure which has a specific secondary electron emission coefficient function associated therewith. The material comprising the spacer structure is tailored to provide a

15 secondary electron emission coefficient of approximately 1 for the spacer assembly when the spacer assembly is subjected to flat panel display operating voltages.

In another embodiment, a coating material is applied to at least a portion of a spacer wall. The coating material is selected to provide a secondary electron emission

20 coefficient of approximately 1 for the spacer assembly when the spacer assembly is subjected to flat panel display operating voltages.

In another embodiment, the present invention is comprised of a spacer structure which has a specific secondary electron emission coefficient function

25 associated therewith. The spacer assembly further includes a coating material applied to at least a portion of the spacer structure. The material comprising the spacer structure and the material comprising the coating material taken in

combination are tailored to provide a secondary electron emission coefficient of approximately 1 for the spacer assembly when the spacer assembly is subjected to flat panel display operating voltages.

5   These and other objects and advantages of the present invention will no doubt become obvious to those of ordinary skill in the art after having read the following detailed description of the preferred embodiments which are illustrated in the various drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiments of the invention and, together with the

5   description, serve to explain the principles of the invention:

FIGURE 1 is a side schematic view of a spacer assembly in which a spacer wall has a coating material applied to a portion thereof in accordance with one embodiment of the present claimed invention.

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FIGURES 2A-2C are a set of Figures comparing secondary electron emission coefficient function (δ), impinging electron energies, and spacer assembly height for the spacer assembly of Figure 1 in accordance with one embodiment of the present claimed invention.

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FIGURE 3 is a side schematic view of a spacer assembly in which a spacer wall has a coating material of varying thickness applied to a portion thereof in accordance with one embodiment of the present claimed invention.

20   FIGURE 4 is a side schematic view of a spacer assembly in which a spacer wall has a first coating material applied to a first portion thereof and a second coating material applied to a second portion thereof in accordance with one embodiment of the present claimed invention.

25   FIGURE 5 is a side schematic view of a spacer assembly in which a spacer wall has a first coating material applied to a first portion thereof and a second coating

material applied to a second portion thereof such that the entire spacer wall is coated in accordance with one embodiment of the present claimed invention.

FIGURE 6 is a flow chart of steps performed during the production of a spacer assembly in which a spacer wall has a first coating material applied to a first portion thereof and a second coating material applied to a second portion thereof in accordance with one embodiment of the present claimed invention.

FIGURE 7 is a schematic diagram of an exemplary computer system having a field emission display device in accordance with one embodiment of the present invention.

FIGURE 8 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the support structure is comprised of pure Al_2O_3 doped with cerium oxide in accordance with one embodiment of the present claimed invention.

FIGURE 9 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of a layered material in accordance with one embodiment of the present claimed invention.

FIGURE 10 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of multi-component transition metal oxide material in accordance with one embodiment of the present claimed invention.

FIGURE 11 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of boron nitride material in accordance with one embodiment of the present claimed invention.

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FIGURE 12 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the support structure is comprised of a material selected from the group consisting of borides, carbides, or nitrides in accordance with one embodiment of the present claimed invention.

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FIGURE 13 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of a material selected from the group consisting of borides, carbides, or nitrides in accordance with one embodiment of the present claimed invention.

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FIGURE 14 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the support structure is comprised of an oxygen releasing material in accordance with one embodiment of the present claimed invention.

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FIGURE 15 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of an oxygen releasing material in accordance with one embodiment of the present claimed invention.

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FIGURE 16 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is

comprised of metal-containing particles in accordance with one embodiment of the present claimed invention.

FIGURE 17 is a cross sectional view of a metal-containing particle of FIGURE 16 in accordance with one embodiment of the present claimed invention.

FIGURE 18 is a cross sectional view of a zeolite-type metal-containing particle of FIGURE 16 in accordance with one embodiment of the present claimed invention.

FIGURE 19 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of cerium oxide doped with lanthanides in accordance with one embodiment of the present claimed invention.

FIGURE 20 is a side schematic view of a spacer assembly in which a support structure is comprised of a material selected according to a selection criteria which considers the free energy of formation of the material in accordance with one embodiment of the present claimed invention.

FIGURE 21 is a side schematic view of a spacer assembly in which a support structure has a coating material disposed thereon and wherein the coating material is comprised of a material selected according to a selection criteria which considers the free energy of formation of the material in accordance with one embodiment of the present claimed invention.

FIGURE 22 is a side schematic view of a spacer assembly in which a support structure has a coating material disposed thereon and wherein the coating material is

comprised of TiAlN in accordance with one embodiment of the present claimed invention.

FIGURE 23 is a side schematic view of a spacer assembly in which a support structure has a coating material disposed thereon and wherein the coating material is comprised of Nd_2O_3 in accordance with one embodiment of the present claimed invention.

FIGURE 24 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of a material selected from the group consisting of Cr_2O_3-Nd_2O_3, Nd_2O_3-MnO, or Cr_2O_3-MnO in accordance with one embodiment of the present claimed invention.

FIGURE 25 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of a material selected from the group consisting of MoS_2 and WS_2 in accordance with one embodiment of the present claimed invention.

FIGURE 26 is a side schematic view of a spacer assembly in which a support structure has a coating material applied thereto wherein the coating material is comprised of double layered material in accordance with one embodiment of the present claimed invention.

The drawings referred to in this description should be understood as not being drawn to scale except if specifically noted.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be

5   understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the present invention, numerous specific details are set forth in order to provide a

10   thorough understanding of the present invention. However, it will be obvious to one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the present invention. Additionally, although the following discussion specifically

15   mentions spacer walls, it will be understood that the present invention is also well suited to the use with various other support structures herein referred to as spacer structures including, but not limited to, posts, crosses, pins, wall segments, T-shaped objects, and the like. However, within the present application, the term spacer structure is intended to include, but not be limited to, the various types of support

20   structures mentioned above.

Referring now to Figure 1, a schematic side sectional view of a spacer assembly 100 in accordance with one embodiment of the present invention is shown. In the present embodiment, spacer assembly 100 is comprised of a spacer structure

25   102 having a coating 104 applied to a portion thereof. In the embodiment of Figure 1, spacer structure 102 is comprised of a combination of materials. More specifically, in the present embodiment spacer structure 102 is comprised of approximately 30

percent chromium oxide (Cr_2O_3), approximately 70 percent alumina (Al_2O_3), with a small amount of titanium (Ti) added as well. Although spacer structure 102 is comprised of such a mixture in the present embodiment, the present invention is also well suited to spacer walls having various other compositions or component ratios.

5   Typically, spacer structure 102 will have a length (from cathode to anode) of 1.25 millimeters, and a width of 50 microns.

    With reference still to Figure 1, a coating material 104 is applied to a portion of spacer structure 102. In the present embodiment coating material 104 is comprised

10   of Cr_2O_3 with approximately 3 percent titanium. Furthermore, in the present embodiment, coating material 104 is applied to spacer structure 102 with a thickness of approximately a few hundred Angstroms. It is within the scope of the present invention, however, to vary the thickness of coating material 104. As shown in Figure 1, in the present embodiment, coating material 104 is applied to the lower

15   portion of spacer structure 102 near where spacer structure 102 is coupled to the cathode, shown as 106, of the field emission display device. Furthermore, in this embodiment, coating material 104 is not applied to spacer structure 102 near where spacer structure 102 is coupled to the anode, shown as 108, of the field emission display device. While in the present embodiment, coating material 104 is comprised

20   of Cr_2O_3 with approximately 3 percent titanium, the present invention is also well suited to the use of various other coating materials which satisfy the conditions set forth below. Additionally, although coating material 104 is applied to the lower portion of spacer structure 102 as shown in Figure 1, the present invention is well suited to various other configurations in which coating material 104 is applied to

25   various other portions of spacer structure 102.

With reference now to Figures 2A-2C, a comparison between secondary emission coefficient function (δ), impinging electron energies, and spacer assembly height for the spacer assembly of Figure 1 is shown. In a conventional field emission display device, electrons are accelerated from the cathode 106 towards the anode 108

5   using an increasing voltage potential. More specifically, the potential is at approximately 0 keV near the cathode 104 of the field emission display device. Thus, in the present invention, the voltage potential is at approximately 0 keV near the base of spacer assembly 100. The voltage potential is gradually increased to a value of approximately 6 keV near the anode 108 of the field emission display device. Thus,

10   in the present invention, the voltage potential is at approximately 6 keV near the top of spacer assembly 100. This increasing voltage potential is graphically illustrated in Figure 2B which plots voltage potential values between cathode 106 and anode 108. It will be understood that electrons which strike spacer assembly 100 of the present embodiment will have an energy approximately equivalent to the voltage potential at

15   that point. Thus, as can be determined by comparing Figure 2B with Figure 2A, in the present embodiment, coating material 104 extends from the base of spacer structure 102 to approximately the point where electrons impinging spacer assembly 100 would have an energy of approximately 3 keV.

20   Referring now to Figure 2C, a graph 202 of secondary electron emission coefficient function (δ) is shown. In graph 202 of Figure 2C, line 204 represents the secondary emission coefficient function for a bare spacer structure 102 of Figures 1 and 2A between 0 keV and 6 keV. Line 206 represents the secondary emission coefficient function for coating material 104 of Figures 1 and 2A between 0 keV and 6

25   keV. In order for a spacer assembly 100 to remain "electrically invisible" (i.e. not deflect electrons passing from the row electrode on the backplate (cathode 106) to pixel phosphors on the faceplate (anode 108)), the secondary electron emission

coefficient function must be kept at or near the value of 1. As shown by line 204 of Figure 2C, the secondary electron emission coefficient function for bare spacer structure 102 is much greater than 1.0 when the incident electron energy is between approximately 0 keV and less than 3 keV. However, the secondary electron emission

5   coefficient function for bare spacer structure 102 is fairly close to a value of 1.0 when the incident electron energy is between approximately greater than 3 keV to a value of 6 KeV. Conversely, as shown by line 206 of Figure 2C, the secondary electron emission coefficient function for coating material 104 of Figures 1 and 2A is fairly close to a value of 1.0 when the incident electron energy is between approximately 0

10 keV and less than 3 keV. However, the secondary electron emission coefficient function for coating material 104 is much less than 1.0 when the incident electron energy is between approximately greater than 3 keV to a value of 6 KeV.

     Thus, the present embodiment compensates for the variation in energy of the

15 electrons which may potentially strike the spacer assembly 100 by coating the lower portion of spacer structure 102 with coating material 104 and leaving the upper portion of spacer structure 102 uncoated or "bare". As a result, the secondary electron emission coefficient function of spacer assembly 100 is at or near a value of 1.0 at the lower portion thereof (due to the presence of coating material 104), and the

20 secondary electron emission coefficient function of spacer assembly 100 is at or near a value of 1.0 where desired along the upper portion thereof (due to the presence of bare spacer structure 102). As a result, spacer assembly 100 of the present embodiment has a plurality of secondary electron emission coefficient functions associated therewith. Moreover, the present embodiment tailors the secondary

25 electron emission coefficient function of spacer assembly 100 by coating a portion of spacer structure 102 with a coating material 104.

In addition to providing an "electrically invisible" spacer assembly 100 by tailoring the secondary electron emission coefficient function to have a value close to 1.0 where desired, the present invention has several other advantages associated therewith. As one example, by not significantly collecting excess charge, the present

5   invention eliminates the need for sophisticated, difficult to manufacture, and expensive features such as electrodes or other devices necessary in some conventional spacer walls to bleed off excess charge. Hence, the present invention can be easily and inexpensively manufactured. Additionally, because spacer assembly 100 of the present embodiment reduces charge accumulation, less charge

10   is present to be drained from the spacer wall. As a result, resistivity specifications for the bulk spacer structure 102 (and coating material 104) can be significantly relaxed. Such relaxed specifications/requirements reduce the cost of spacer structure 102 and coating material 104. Thus, the present invention can reduce manufacturing costs. Less charging also allows the resistivity of the wall material to be increased

15   which decreases leakage current through the wall. This leads to greater field emission display efficiency.

Also, manufacturing of a spacer assembly in accordance with the present embodiment has distinct advantages associated therewith. For example, in the

20   embodiment of Figure 2A, the location of coating material 104 on spacer structure 102 can be altered slightly without dramatically compromising the benefits associated with the present invention. As a result, manufacturing tolerances can be loosened enough to significantly reduce manufacturing costs without severely compromising performance.

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As yet another advantage, spacer assembly 100 has good stability. That is, in addition to tailoring the secondary electron emission coefficient function to a value of

near 1.0 along the entire length thereof, spacer assembly 100 may not degrade severely when subjected to electron bombardment, depending on the materials used for the spacer structure and the coating or coatings. For example, if the coating is less stable than the spacer structure to electron bombardment, the configuration

5   shown in Figure 2A will not degrade as quickly under operation, because by far more electrons strike the upper portion of the spacer, where there is no coating. Another was to look at this is that it relaxes the stability requirements of the coating. By not degrading, spacer assembly 100 does not significantly contribute to contamination of the vacuum environment of the field emission display device. Additionally, the

10   materials comprising spacer assembly 100 of the present embodiment (i.e. Cr_2O_3, Al_2O_3, and Ti in spacer structure 102 and Cr_2O_3 in coating material 104) can easily have contaminant carbon removed or washed therefrom prior to field emission display sealing processes. Actually, in one embodiment, any uncovered spacer will be less likely to collect carbon, compared to the present coating Cr_2O_3. Collecting

15   carbon is not necessarily deleterious, only when electrons also strike that surface. By restricting the coating to the lower half of the wall, fewer electrons strike the carbon coated surfaces, again leading to a more stable configuration. Also, the materials comprising spacer assembly 100 of the present embodiment do not deleteriously collect carbon after the field emission display seal process. As a result, the present

20   embodiment is not subject to the carbon-related contamination effects associated with conventional uncoated spacer walls.

      With reference now to Figure 3, another embodiment of a spacer assembly 300 in accordance with the present claimed invention is shown. As in the embodiment of

25   Figure 1 and Figure 2A, in this embodiment, spacer assembly 300 is comprised of a spacer structure 102 having a coating 302 applied to a portion thereof. In the embodiment of Figure 3, spacer structure 102 is comprised of the same materials

described in detail above in conjunction with the embodiment of Figures 1 and 2A. However, the present invention is also well suited to spacer walls having various other compositions or component ratios. Additionally, in the present embodiment, coating material 302 is comprised of Cr_2O_3, however, the present embodiment is also

5   well suited to the use of various other coating materials.

With reference still to the embodiment of Figure 3, spacer structure 102 has a coating material 302 applied thereto with varying thickness. In this embodiment, the varying thickness of coating material 302 correspondingly varies with the energy of

10   the electrons which may impinge spacer assembly 300 such that the combination of the secondary electron emission coefficient function of coating material 302 and the secondary electron emission coefficient function of underlying spacer structure 102 combine to provide a total secondary electron emission coefficient function having a value of at or near 1.0 where desired along spacer assembly 300. More specifically,

15   when coating material 302 is deposited to a sufficient thickness, the secondary electron emission coefficient function will be that of coating material 302. Conversely, when no coating material 302 is present, the secondary electron emission coefficient function will be that of spacer structure 102. However, when coating material 302 is thin enough (e.g. at region 304), the secondary electron emission

20   coefficient function will be comprised partially of the secondary electron emission coefficient function of coating material 302 and partially of the secondary electron emission coefficient function of underlying spacer structure 102. Thus, the present embodiment takes into account the fact that the energy of impinging electrons increases from a value of approximately 0 keV at the region near cathode 106 to a

25   value of approximately 6 keV at the region near anode 108. The present embodiment then tailors the thickness of coating 302 such that the combination of the secondary electron emission coefficient function of coating material 302 and the secondary

electron emission coefficient function of underlying spacer structure 102 will provide a total secondary electron emission coefficient function having a value at or near 1.0 where desired. Thus, the present embodiment generates a spacer assembly having a plurality of position varying secondary electron emission coefficient functions

5   associated therewith.

With reference now to Figure 4, a side schematic view of a spacer assembly 400 is shown. In the present embodiment, a spacer structure 102 has a first coating material 402 applied to a first portion thereof and a second coating material 404

10   applied to a second portion thereof. In the embodiment of Figure 4, spacer structure 102 is comprised of the same materials described in detail above in conjunction with the embodiment of Figures 1, 2A, and 3. However, the present invention is also well suited to spacer walls having various other compositions or component ratios. Additionally, in the present embodiment, second coating material 404 is comprised of

15   Cr_2O_3, however, the present embodiment is also well suited to the use of various other coating materials. In the embodiment of Figure 4, first coating material 402 is comprised of Nd_2O_3. As shown in Figure 4, first coating material 402 is exposed only where impinging electrons will have an energy in the range of approximately 2-4 keV. Thus, by selecting a material (e.g. Nd_2O_3) which has a secondary electron emission

20   coefficient function having a value of at or near 1.0 for such a potential range, the present embodiment tailors the overall secondary electron emission coefficient function to the desired value. That is, the present embodiment has a coating material 404 with a secondary electron emission coefficient function of at or near 1.0 for lower energies (e.g. 0-2 keV) disposed near cathode 106. The present embodiment then has

25   a coating material 402 with a secondary electron emission coefficient function of at or near 1.0 for mid-range energies (e.g. 2-4 keV) disposed near the middle portion of spacer structure 102. Finally, the present embodiment has an exposed bare spacer

structure 102 with a secondary electron emission coefficient function of at or near 1.0 for higher energies (e.g. 4-6 keV) disposed near anode 108. The present embodiment is also well suited to varying the location of, thickness of, or materials comprising the first and second coating to precisely tailor the resultant secondary electron emission

5   coefficient function wherever desired along spacer assembly 400. Additionally, the present embodiment is also well suited to using more than two coating materials to achieve the desired resultant secondary electron emission coefficient function.

       With reference now to Figure 5, a side schematic view of a spacer assembly

10   500 in which a spacer wall has a first coating material 502 applied to a first portion thereof and a second coating material 504 applied to a second portion thereof. In the embodiment of Figure 5, the entire surface of spacer structure 102 is coated. In this embodiment, spacer structure 102 is comprised of the same materials described in detail above in conjunction with the embodiment of Figures 1, 2A, 3, and 4. However,

15   the present invention is also well suited to spacer walls having various other compositions or component ratios. Additionally, in the present embodiment, second coating material 504 is comprised of Cr_2O_3, however, the present embodiment is also well suited to the use of various other coating materials. In the embodiment of Figure 5, first coating material 502 is comprised of Nd_2O_3. As shown in Figure 5, first

20   coating material 502 is exposed only where impinging electrons will have an energy in the range of approximately 3-6 keV. Thus, by selecting a material (e.g. Nd_2O_3) which has a secondary electron emission coefficient function having a value of at or near 1.0 for such a potential range, the present embodiment tailors the overall secondary electron emission coefficient function to the desired value. That is, the present

25   embodiment has a coating material 504 with a secondary electron emission coefficient function of at or near 1.0 for lower energies (e.g. 0-3 keV) disposed near cathode 106. The present embodiment then has a coating material 502 with a

secondary electron emission coefficient function of at or near 1.0 for higher energies (e.g. 3-6 keV) disposed near anode 108. In this embodiment, none of bare spacer structure 102 is exposed. The present embodiment is also well suited to varying the location of, thickness of, or materials comprising the first and second coating to

5   precisely tailor the resultant secondary electron emission coefficient function wherever desired along spacer assembly 500. Additionally, the present embodiment is also well suited to using more than two coating materials to achieve the desired resultant secondary electron emission coefficient function.

10   With reference now to Figure 6 a flow chart 600 of steps performed during the production of a spacer assembly in accordance with the present claimed invention is shown. As shown in Figure 6, at step 602, the present invention first provides a spacer wall. In the present embodiment, the spacer wall (e.g. spacer structure 102 of Figure 1, 2A, 3, 4, and 5) is comprised of a combination of materials. More

15   specifically, in the present embodiment spacer structure 102 is comprised of approximately 30 percent chromium oxide (Cr_2O_3), approximately 70 percent alumina (Al_2O_3), with a small amount of titanium (Ti) added as well. Although spacer structure 102 is comprised of such a mixture in the present embodiment, the present invention is also well suited to spacer walls having various other

20   compositions or component ratios. Typically, spacer structure 102 will have a length (from cathode to anode) of 1.25 millimeters, and a width of 50 mils.

Next, at step 604, the present embodiment applies a first coating material (e.g. coating material 104 of Figure 1) to spacer wall provided in step 602. In one

25   embodiment, the coating material is comprised of Cr_2O_3. Furthermore, in the present embodiment, the coating material is applied to the underlying spacer wall with a thickness of approximately a few hundred Angstroms. It is within the scope of

the present invention, however, to vary the thickness of the coating material. The present invention is also well suited to the use of various other coating materials which satisfy the conditions set forth above. Additionally, the present invention is well suited to varying the location on spacer structure 102 to which the coating

5   material is applied. That is, the present invention is, for example, well suited to applying coating material proximate to where the spacer wall is coupled to a cathode of a field emission display device, and/or not applying the coating material proximate to where the spacer wall is coupled to an anode of a field emission display device.

10   Referring now to step 606, the present embodiment then applies a second coating material (e.g. coating material 404 of Figure 4) to the spacer assembly. In one embodiment, the second coating material overlies a first coating material (e.g. coating material 402 of Figure 4). In so doing, the present embodiment tailors the overall secondary electron emission coefficient function to a desired value. That is,

15   the present embodiment has a coating material (e.g. the second coating material) with a secondary electron emission coefficient function of at or near 1.0 for lower energies (e.g. 0-3 keV) disposed near the cathode of the field emission display device. The present embodiment then has another coating material (e.g. the first coating material) with a secondary electron emission coefficient function of at or near 1.0 for

20   higher energies (e.g. 3-6 keV) disposed near the anode of the field emission display device. The present embodiment is also well suited to varying the location of, thickness of, composition of, or materials comprising the first and second coating to precisely tailor the resultant secondary electron emission coefficient function wherever desired along the spacer assembly.

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With reference now to Figure 7, an exemplary computer system 700 used in accordance with the present embodiment is illustrated. It is appreciated that system

700 of Figure 7 is exemplary only and that the present invention can operate within a number of different computer systems including personal computer systems, laptop computer systems, personal digital assistants, telephones (e.g. wireless cellular telephones), in-vehicle systems, general purpose networked computer systems,

5   embedded computer systems, and stand alone computer systems. Furthermore, as will be described below in detail, the components of computer system 700 reside, for example, in a client computer and/or in the intermediate device coupled to computer system 700. Additionally, computer system 700 of Figure 7 is well adapted having computer readable media such as, for example, a floppy disk, a compact disc, and the

10   like coupled thereto. Such computer readable media is not shown coupled to computer system 700 in Figure 7 for purposes of clarity.

       System 700 of Figure 7 includes an address/data bus 702 for communicating information, and a central processor unit 704 coupled to bus 702 for processing

15   information and instructions. Central processor unit 704 may be, for example, an 80x86-family microprocessor or various other type of processing unit. System 700 also includes data storage features such as a computer usable volatile memory 706, e.g. random access memory (RAM), coupled to bus 702 for storing information and instructions for central processor unit 704, computer usable non-volatile memory

20   708, e.g. read only memory (ROM), coupled to bus 702 for storing static information and instructions for the central processor unit 704, and a data storage unit 710 (e.g., a magnetic or optical disk and disk drive) coupled to bus 702 for storing information and instructions. System 700 of the present invention also includes an optional alphanumeric input device 712 including alphanumeric and function keys is coupled

25   to bus 702 for communicating information and command selections to central processor unit 704. System 700 also optionally includes a cursor control device 714 coupled to bus 702 for communicating user input information and command

selections to central processor unit 704. System 700 of the present embodiment also includes an field emission display device 716 coupled to bus 702 for displaying information.

5   Referring still to Figure 7, optional cursor control device 714 allows the computer user to dynamically signal the two dimensional movement of a visible symbol (cursor) on a display screen of display device 716. Many implementations of cursor control device 714 are known in the art including a trackball, mouse, touch pad, joystick or special keys on alphanumeric input device 712 capable of signaling

10   movement of a given direction or manner of displacement. Alternatively, it will be appreciated that a cursor can be directed and/or activated via input from alphanumeric input device 712 using special keys and key sequence commands. The present invention is also well suited to directing a cursor by other means such as, for example, voice commands.

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       With reference now to Figure 8, a schematic side sectional view of a spacer assembly 800 in accordance with one embodiment of the present invention is shown. In the present embodiment, spacer assembly 800 is comprised of a spacer structure 802. Typically, spacer structure 802 will have a length (from cathode to anode) of

20   approximately 1.25 millimeters, and a width of approximately 50 microns. Additionally, although portions of the following discussion may specifically mention spacer walls, it will be understood that the present invention is also well suited to use with various other support structures herein referred to as spacer structures including, but not limited to, posts, crosses, pins, wall segments, T-shaped objects,

25   and the like. However, within the present application, the term spacer structure is intended to include, but not be limited to, the various types of support structures mentioned above. Furthermore, although the following discussion may specifically

recite use of the various embodiments of the present invention in a field emission display device, the various embodiments of the present invention are well suited to use in various other flat panel display devices. Also, although embodiments of the present invention which refer to the use of a coating material may show the coating

5   material applied to the entire portion of an underlying spacer structure, the present invention is well suited to various other configurations in which the coating material is applied to only specific portions of the underlying spacer structure.

Referring still to Figure 8, the secondary electron emission coefficient of

10   support structure 802 plays a critical part in achieving invisibility of the support structure, as charging on the wall can lead to beam deflection, resulting in non-activated phosphor on either side of the wall. To achieve no or very low charging the secondary electron emission coefficient of the wall material must be around one (1) for all range of field emission display operating voltages (e.g. .5kV to 8 kV). In the

15   present embodiment, support structure 802 contains cerium oxide. In one embodiment, the measured secondary electron emission coefficient of cerium oxide for field emission display operating voltage range of .5kV to 7 kV gives a secondary electron emission coefficient of approximately .75 to 1.77. More specifically, the spacer structure of the present embodiment is pure Al_2O_3 doped with cerium oxide. In

20   such an embodiment, the spacer structure achieves fine smoothness and great strength. For example, spacer structure 802 of the present embodiment, has a hardness of between that of Al_2O_3 (on the Mohs scale, Al_2O_3 has a hardness of 7) and cerium oxide (on the Mohs scale, cerium oxide has a hardness of 6).

25   With reference now to Figure 9, another embodiment 900 of the present invention is shown. In this embodiment, a spacer structure 902 has a coating material 904 applied to a portion thereof. In the present embodiment, coating

material 904 is applied to spacer structure 902 with a thickness on the order of Angstroms. It is within the scope of the present invention, however, to vary the thickness of coating material 904. Additionally, although coating material 904 is applied to the entire portion of spacer structure 902 as shown in Figure 9, the present

5   invention is well suited to various other configurations in which coating material 904 is applied to only specific portions of spacer structure 902.

Referring still to Figure 9, as mentioned above, it is desired to achieve a secondary electron emission coefficient of approximately 1 for the operating voltages

10   of the flat panel display. The present embodiment provides a material which achieves relatively weak scattering of high energy incident or primary electrons and very strong scattering of lower energy secondary electrons. More particularly, in the present embodiment, coating material 904 is comprised of a layered material. In the present embodiment, the layered material is deposited with its basal planes parallel

15   to the face of the ceramic support structure 902. In so doing, coating material 904 of the present embodiment achieves, a much reduced secondary electron emission coefficient (i.e. closer to the value of 1) than that of comparable materials with random orientations.

20   With reference still to Figure 9, in one embodiment, the layered material comprising coating material 904 is a semimetal. Moreover, in one specific embodiment, the layered material of coating material 904 is comprised a material such as graphite, MoS_2, $MoSe_2$, and the like.

25   Referring now to Figure 10, another embodiment 1000 of the present invention is shown. In the embodiment of Figure 10, a support structure 1002 has a coating material 1004 disposed thereon. In this embodiment, coating material 1004 is

comprised of a transition metal oxide compound. Such a coating material decreases
the electron escape depth, lambda. Such a decrease in the electron escape depth,
lambda, is accomplished by forming solid solutions in quaternary oxides whereby a
random ordering is induced in either ion valence, unoccupied d-states in the conduction

5   band, or in ionic radii. Hence, coating material 1004 of the present embodiment
decreases wall visibility (i.e. increases invisibility). Additionally, coating material
1004 of the present embodiment meets the desired requisite properties of low
secondary electron emission, high resistivity, high thermal stability, high stability
under electron beam bombardment, and high resistance to hydrocarbon

10   contamination. Furthermore, coating material 1004 reduces the secondary electron
emission of support assembly 1000 without otherwise increasing the electrical
conductively of support assembly 1000. Also, coating material 1004 achieves the
above properties and does not degrade upon thermal treatments up to and including
500 degrees Centigrade. Coating material 1004 achieves the above properties and

15   does not degrade upon prolonged exposure to electron flux during operation of the
display. As yet another benefit, coating material 1004 of the present embodiment
achieves the above properties and does not degrade when exposed to the types of
gaseous chemicals that are typically encountered during the assembly and sealing
processes typical of emissive displays.

20

Referring still to Figure 10, coating material 1004 is comprised in one
embodiment, of ternary and quaternary transition metal oxides. More specifically, in
one embodiment, coating material 1004 has the perovskite composition: ABO_3,
where A and B are transition metals. In another embodiment, coating material 1004

25   is comprised of, for instance, any of the lanthanide elements can be mixed together as
a solution comprising the "A" atom position. (e.g. $(Nd_x, Pr_{1-x}) TiO_3$). In still another
embodiment, coating material 1004 is comprised of a A_2BO_4 composition such as, for

example, $La_xBa_{(2-x)}CuO_4$, where A and B are transition metals. One of the unique and controllable properties of these coating materials lies in their ability to scatter internal secondary electrons, essentially trapping the secondaries by forcing them to lose their energy before escaping from the solid. Additionally, certain quaternary

5   compositions can be found which will decrease the "escape length" lambda which is characteristic of this property. Hence, in one embodiment, coating material 1004 is comprised of a material in which atoms are mixed on the "A" site with alternating valence. An example would be $La_xBa_{(1-x)}TiO_3$. In this case the La and Ba would occupy similar lattice sites. The La will be a 3+ ion while the Ba will be a 2+ ion. The

10   random nature of their local electrical fields will encourage electron scattering and reduce lambda.

        Referring still to Figure 10, in another embodiment, coating material 1004 is comprised of a material where metals of the same valence are mixed but where the

15   materials have different energy unoccupied states in the band gap. An example would be $SrTi_xZr_{(1-x)}O_3$. In this embodiment, both Ti and Zr have the configuration 4+, but since they have unoccupied d-orbitals at different energies in the gap there is an effective "roughness" or randomness near the bottom of the conduction band which will facilitate electron scattering and reduce lambda.

20

        Referring again to Figure 10, is still another embodiment, coating material 1004 is comprised of a material in which atoms of different size are mixed on the same lattice site. In one such embodiment, coating material 1004 is comprised of $La_xY_{(1-x)}CrO_3$. In this embodiment, both La and Y will have the valence 3+ but will

25   have significantly different ionic radii. The result is that the lattice exists in relative tension around the Y atoms while it exists in relative compression around the La

atoms. As a result the band gap will have randomly varying energies which will facilitate electron scattering and reduce lambda.

With reference now to Figure 11, another embodiment 1100 of the present
5   invention is shown. In the embodiment of Figure 11, a coating material 1104 has the proper combination of electrical properties such that, when deposited on support structure 1102, charging will be minimized and support structure 1102 will be invisible. In the prior art, it has been found that carbon with a short range graphitic structure exhibits low secondary electron emission. However, the electrical
10   conductively of graphite prohibits the use of thick coatings on the surface of support structures such as support structure 1102. In order to obtain sufficiently resistive coatings, carbon film thicknesses on the order of 15 Angstroms are needed. Thicknesses in this range are difficult to deposit in a reproducible manner. However, the boron nitride composition of the present embodiment is significantly less
15   conducting then graphite and the present composite of boron nitride and carbon produces a coating with low secondary electron emission and sufficiently great resistivity to permit the use of much thicker layers. Hence, coating material 1104 of the present embodiment is well suited to having a thickness of greater than approximately 15 Angstroms.
20

Referring still to Figure 11, coating material 1104 of the present embodiments utilizes boron nitride alone or in combination with carbon films to obtain a material with a crystal structure which produces low secondary electron emissions. In addition to this previously observed crystal structure, the present coating material
25   1104 of boron nitride alone or in combination with carbon has greater resistivity than carbon alone. As yet another advantage, coating material 1104 of the present embodiments (i.e. boron nitride alone or in combination with carbon films) shares

many similar mechanical properties with graphite due to the similarity of their crystal structures.

With reference now to Figure 12, another embodiment 1200 of the present
5   invention is shown. In this embodiment, support structure 1202 is comprised of at least one of the following materials: borides, carbides or nitrides. In such an embodiment, the materials are formulated in bulk form (e.g. as a sintered ceramic body). These materials are specific compounds that have boron (B), carbon (C) or nitrogen (N) as one of the components in them. For example, BN corresponds to
10   boron nitride. Several distinct advantages are realized by utilizing borides, carbides, or nitrides as the spacer structure in accordance with the present embodiments. For example, such materials are very strongly covalent in nature and hence have the following generic properties: (i) they are very hard and mechanically strong; (ii) they have very high melting points; (iii) they are generally very oxidation resistant ; (iv)
15   they have a large band gap and hence behave like wide bandgap semiconductors; and (v) they have very high intrinsic resistivities.

With reference now to Figure 13, another embodiment 1300 of the present invention is shown. In this embodiment, a support structure 1302 has a coating
20   material 1304 applied thereto (In one embodiment, spacer structure 1302 is also comprised of at least one of the following materials: borides, carbides or nitrides). In the present embodiment, coating material 1304 is comprised of at least one of the following materials: borides, carbides or nitrides. In such an embodiment, the materials are formulated as a thin film. These materials are specific compounds that
25   have boron (B), carbon (C) or nitrogen (N) as one of the components in them. For example, BN corresponds to boron nitride. Several distinct advantages are realized by utilizing borides, carbides, or nitrides as the coating material in accordance with

the present embodiments. For example, such materials are very strongly covalent in nature and hence have the following generic properties: (i) they are very hard and mechanically strong; (ii) they have very high melting points; (iii) they are generally very oxidation resistant; (iv) they have a large band gap and hence behave like wide

5 bandgap semiconductors; and (v) they have very high intrinsic resistivities. Additionally, coating material 1304 of the present embodiment, is well suited to application to spacer structure 1302 using a variety of processes. These processes include, for example, pulsed laser ablation to deposit thin films of these materials. Furthermore, large areas can be coated using chemical vapor deposition, sputtering

10 or even liquid state processing routes.

With reference now to Figure 14, another embodiment 1400 of the present invention is shown. In the present embodiment, spacer structure 1402 includes material which releases oxygen. Referring still to Figure 14, in one embodiment, the

15 oxygen releasing material of spacer structure 1402 is comprised of oxidizers such as perchlorates, peroxides, and nitrates. The key criteria for the chosen material are: 1) highly insulating both before and after releasing oxygen, but not so insulating as to prevent charge from passing from any coating material into spacer structure 1402; 2) stable through the seal cycle temperature (< 400C); 3) somewhat unstable under

20 electron bombardment; and 4) possible to deposit a thin (of order 100 Angstroms) layer of the material by sputtering.

More specifically, in one embodiment, spacer structure 1402 includes a perchlorate compound such as $KClO_4$ in the surface layers thereof. In so doing, the

25 present embodiment prevents oxygen loss in the wall surface and eliminates surface contamination by oxidation. The oxygen releasing material of the present embodiment is stable through the seal process, but breaks down releasing oxygen

gradually over the life of the tube under bombardment by Rutherford scattered electrons. As a specific example, $KClO_4$ is stable to 400° C.

Referring still to Figure 14, in an embodiment in which spacer structure 1402

5   has a low SEEC coating material disposed thereon, the oxygen releasing material of the present embodiment is mixed within or placed under the coating material. In an embodiment in which spacer structure 1402 has no coating material disposed thereon, the oxygen releasing material is placed on the wall surface. The oxygen is preferably released mainly in the form of O ions and not O_2 gas.

10

One feature of the present embodiment, is the ability to replenish the lost oxygen in spacer structure 1402 and to produce excess oxygen to "burn" away (to CO or CO_2) carbon contamination on the spacer structure 1402. The CO and CO_2 gas products will be pumped away by the getter in the display device. Small amounts of

15   excess O_2 can also be pumped away. Locally generating oxygen, as is accomplished in the present embodiment, is superior to putting oxygen in the background gas of the display device. Oxygen will be released locally in proportion to the amount of electron beam flux and roughly proportional to the "damage" (oxygen loss and carbonaceous layer formation) being done by the electron beam. The oxygen will be in a more

20   reactive form as ions than as O_2 molecules which must be cracked at the surface of support structure 1402 before they can react with support structure 1402 or contamination. Large quantities of oxygen cannot be left in the background gas of the display device because it would cause deterioration of the field emitters and overload the getter reducing the pumping rate for other contaminants.

25

With reference next to Figure 15, another embodiment 1500 of the present invention is shown, In this embodiment, a spacer structure 1502 has a coating

material 1504 applied thereto. In the present embodiment, coating material 1504 includes material which releases oxygen. In one embodiment, the oxygen releasing material of coating material 1504 is comprised of oxidizers such as perchlorates, peroxides, and nitrates. The key criteria for the chosen material are: 1) highly

5   insulating both before and after releasing oxygen, but not so insulating as to prevent charge from passing from coating material 1504 into spacer structure 1502; 2) stable through the seal cycle temperature (< 400C); 3) somewhat unstable under electron bombardment; and 4) possible to deposit a thin (of order 100 Angstroms) layer of the material by sputtering.

10

More specifically, in one embodiment, coating material 1504 includes a perchlorate compound such as $KClO_4$. In so doing, the present embodiment prevents oxygen loss in coating material 1504 and eliminates surface contamination by oxidation. The oxygen releasing material of the present embodiment is stable through

15   the seal process, but breaks down releasing oxygen gradually over the life of the tube under bombardment by Rutherford scattered electrons. As a specific example, $KClO_4$ is stable to 400° C.

Referring still to Figure 15, in this embodiment oxygen will preferably is

20   released mainly in the form of O ions and not O_2 gas. In the present embodiment, the thickness of coating material 1504 should be chosen to be the minimum needed to release oxygen at a sufficient rate to prevent changes in the conductivity of the spacer assembly (e.g. an underlying spacer structure 1502 and coating material 1504) over the life of the display device.

25

With reference now to Figure 16, another embodiment 1600 of the present invention is shown. In this embodiment, ceramic and other insulating spacer

structures 1602 tend to have higher secondary electron emission coefficients (SEECs) than metal support structures due to the lack of "free electrons". The present embodiment lowers the SEEC of spacer assemblies which include insulating spacer structures (e.g. spacer structure 1602) by dispersing metal-containing

5   particles, typically shown as 1604, on spacer structure 1602.

Referring now to Figure 17, a side sectional view of metal-containing particle 1604 is shown. In the present embodiment, metal-containing particle 1604 is comprised of a core of metal material 1704 which is electrically isolated in an

10   insulating shell 1702, thus the resistivity of spacer structure 1602 will not be significantly affected by the presence of metal-containing particles 1604 on spacer structure 1602. In one embodiment, core of metal material 1704 has a diameter of approximately 1,000-10,000 Angstroms through powder metallurgy. Furthermore, in one embodiment, insulating shell 1702 has a thickness of approximately 20-200

15   Angstroms.

There are at least two methods for making metal-containing particles 1604 of the present embodiment. In one embodiment, metal-containing particles 1604 are prepared by reacting metal powder in the form of a sphere with oxygen or nitrogen,.

20   The SEEC value of metal-containing particles 1604 will be that of insulating shell 1702 at low voltage (when the penetration depth of the electrons is less than the shell thickness). However, the SEEC value of metal-containing particles 1604 will approach that of metal core 1704 at high voltage (when the penetration depth of the electrons is greater than the shell thickness). The energy of the transition depends,

25   therefore, on the shell thickness. Thus, in order to control the overall charging behavior of spacer structures coated with metal-containing particles it is necessary to control the shell thickness in the range of 20 to 200 Angstroms.

Referring still to Figure 17, in one embodiment, metal core of material 1704 of metal-containing particle 1604 is formed of a material selected from the group consisting of Si, Al, Ti, Cr, Zr, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb,

5   and Lu. Insulating shell 1702 is formed by reacting metal core of material 1704 with oxygen for controlled times at controlled temperatures. In another embodiment, metal core of material 1704 of metal-containing particle 1604 is formed of a material selected from the group consisting of Si, Al, Ti, Cr, Zr, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu, and insulating shell 1702 is formed by reacting metal

10   core of material 1704 with nitrogen for controlled times at controlled temperatures.

With reference now to Figure 18, another embodiment of the metal-containing particles is shown. In this embodiment, "free electrons" are introduced by impregnating metal into a porous matrix, a good host structure would be that of a

15   zeolite 1800 which is described as connected dumbbells. For example, in a typical zeolite 1800 there is enough space to accommodate metal clusters (1-8 atoms) in the head of the dumbbell (so-called Sodalite Cage 1802) but no space for metal atoms in the stick of the dumbbells (the channels 1804). This structure 1800 allows for the introduction of isolated metal clusters into an insulating host.

20

Additionally, the present embodiment, is well suited to using various means to apply metal-containing particles 1604 to support structure 1602. For example, metal-containing particles 1604 can be coated to support structure 1602 by employing dip-coating or spray techniques. If a dense aggregation of metal-containing

25   particles 1604 is desired, metal-containing particles 1604 are suspended in a colloidal solution and made to adhere to support structure 1602 and to each other by controlling the drying process. The process requires design of a "sol" that stabilizes

the surface energy between the shell of metal-containing particles 1604 and the solution. A secondary advantage of this technique is that a dense aggregation of metal-containing particles 1604 constitutes a "porous coating" and gains additional reductions in secondary emission (SEEC) due to its morphology.

5

Furthermore, in an embodiment where one is concerned about current arcing from one metal-containing particle 1604 to another metal-containing particle 1604 (i.e. tunneling currents through the insulating shell are substantial), a coating is employed where metal-containing particles 1604 on average do not touch each other. In such an embodiment, metal-containing particles 1604 are deposited at a density where the average spacing is slightly larger than the diameter of metal-containing particles 1604. It is possible to achieve a dense coating (> 50 percent areal coverage by metal-containing particles 1604) and still prevent the clustering or aggregation of metal-containing particles 1604 by means of an electrophoresis technique. In this case the "sol" from which the coatings are derived maintains an electrical charge on each of the metal-containing particles 1604 causing them to deposit as an ordered or well-spaced array instead of a random or clustered array.

With reference now to Figure 19, another embodiment 1900 of the present invention is shown. CeO_2 is known to lose oxygen upon anneal in vacuum or reducing atmospheres. Additionally, electron bombardment of CeO_2 coated support structures at temperatures below 100 C also leads to oxygen loss and significant reductions in resistivity of the support structures.

In the present embodiment, CeO_2 is doped to increase the resistivity of CeO_2 and the doped CeO_2 is then used as a coating material. In particular, in one embodiment, the CeO_2 is doped with lanthanide ions (Y, La, etc.) and the material is

used as a coating material 1904 for an underlying support structure 1902. The lanthanide ions (Y, La, etc.) will quench all electronic conductivity in CeO_2 leaving only ions (metal substitutional anions and oxygen vacancy cations) as charge carriers.

5

Referring still to the embodiment of Figure 19, because the lanthanide ions in coating material 1904 compensate for all the electronic charge carriers, the resistivity will no longer be sensitive to oxygen stoichiometry, oxygen vacancy concentrations, and/or oxygen partial pressures. Hence, the present embodiment

10   provides a more-stable support structure coating material 1904.

In the another embodiment, the CeO_2 is doped with Cr and the material is used as a coating material 1904 for an underlying support structure 1902. The Cr will completely quench all electronic conductivity in CeO_2 leaving only ions (metal

15   substitutional anions and oxygen vacancy cations) as charge carriers. Furthermore, in this embodiment, because the Cr ions in coating material 1904 compensate for all the electronic charge carriers, the resistivity will no longer be sensitive to oxygen stoichiometry, oxygen vacancy concentrations, and/or oxygen partial pressures. Hence, the present embodiment provides a more-stable support structure coating

20   material 1904.

In the another embodiment, the CeO_2 is doped with Ni and the material is used as a coating material 1904 for an underlying support structure 1902. The Ni will completely quench all electronic conductivity in CeO_2 leaving only ions (metal

25   substitutional anions and oxygen vacancy cations) as charge carriers. Furthermore, in this embodiment, because the Ni ions in coating material 1904 compensate for all the electronic charge carriers, the resistivity will no longer be sensitive to oxygen

stoichiometry, oxygen vacancy concentrations, and/or oxygen partial pressures. Hence, the present embodiment provides a more-stable support structure coating material 1904.

5   Referring now to Figure 20, another embodiment 2000 of the present invention is shown. In the present embodiment, a selection criteria is provided for the bulk material of spacer structure 2002 based on the free energy of formation (ΔG). The more negative the free energy of formation is, the more stable is the material system. As a corollary, material degradation of spacer structure 2002 will increase with an

10   increase in ΔG. Furthermore, thermal annealing is known to improve the stability of spacer structure 2002. Even if the material for support structure 2002 is thermodynamically stable (based on data for the crystalline materials taken from CRC Handbook), other factors such as kinetic, temperature, affinity to hydrocarbon, high electric field, electron beam bombardment and the deviation from crystallinity of

15   the material can aggravate the degradation mechanism to different extents.

       In the present embodiment, the selection criteria for support structure 2002 is based on its stability. If the choice passes this first principle criteria, then the selection criteria for support structure 2002 is based on the electrical resistivity,

20   temperature coefficient of resistance (TCR), thermal conductivity (k), SEEC etc. The analysis presented here, applies to single oxide and non-oxide materials. However, the invention of the present embodiment is also applicable to binary and higher systems.

25   Referring now to Figure 21, another embodiment 2100 of the present invention is shown. In the present embodiment, a selection criteria is provided for the coating material 2104 overlying spacer structure 2002 based on the free energy of formation

(ΔG). The more negative the free energy of formation is, the more stable is the material system. As a corollary, material degradation of coating material 2104 will increase with an increase in ΔG. Furthermore, thermal annealing is known to improve the stability of coating material 2104. Even if the material for coating

5   material 2104 is thermodynamically stable (based on data for the crystalline materials taken from CRC Handbook), other factors such as kinetic, temperature, affinity to hydrocarbon, high electric field, electron beam bombardment and the deviation from crystallinity of the material can aggravate the degradation mechanism to different extents.

10

In the present embodiment, the selection criteria for coating material 2104 is based on its stability. If the choice passes this first principle criteria, then the selection criteria for coating material 2104 is based on the electrical resistivity, temperature coefficient of resistance (TCR), thermal conductivity (k), SEEC etc.

15   The analysis presented here, applies to single oxide and non-oxide materials. However, the invention of the present embodiment is also applicable to binary and higher systems.

While thermal annealing may partially improve stability (through partial

20   crystallization), bulk material processing (sintering) at temperatures higher than annealing temperature can be a better approach to form a spacer structure and overlying coating material at the same time.

With reference now to Figure 22, another embodiment 2200 of the present

25   invention is shown. The present embodiment pertains to the control of the resistivities of spacer assemblies by using coating materials 2204 such as borides, carbides and nitrides by deposition of a thin coating of TiAlN (or (Ti, Al)N and other

materials) which are disposed over an underlying support structure 2202. The relative molar concentrations of the base material, i.e., borides, carbides and nitrides with TiAlN determines the effective resistivity of the mixture.

5   Referring still to Figure 22, boron nitride has many attractive features such as high resistivity, mechanical strength, the ability to maintain its structural and chemical integrity at elevated temperatures and excellent oxidation resistance. In terms of its use as a support structure, it has desirable secondary electron emission properties. For example, the SEEC value at 1 KeV is of the order of 1.8, which is
10   either commensurate or lower than that of the conventionally used support structure material. However, it has been determined that the resistivity of the thin film of boron nitride is 10^{12} Ω.cm or higher and hence, larger than that desirable for such applications. The present embodiment describes a efficient and manufacturable method to systematically control the resistivity of boron nitride, while maintaining its
15   low SEEC value.

       Referring again to Figure 22, in one embodiment, a thin layer of TiN or (Ti, Al)N is deposited onto the surface of a boron nitride layer that is deposited onto the surface of support structure 2202. In another embodiment, a thin layer of (Ti, Al)N is
20   deposited onto the surface of a boron nitride layer that is deposited onto the surface of support structure 2202. The deposition of the present embodiment is carried out in the presence of N_2 at a partial pressure in the range 20-100 mTorr. TiN and (Ti, Al)N are both metallic with resistivities of the order of 50-100 $\mu\Omega$.cm at room temperature. This thin layer thickness can vary from 10-300 A, while the underlying boron nitride
25   layer thickness can vary from 50-2000A. Although such dimensions are recited in the present embodiment, the present invention is well suited to using various other dimensional parameters.

Referring still to Figure 22, subsequent to this deposition step, the whole composite stack is annealed at an elevated temperature to facilitate chemical diffusion. The annealing temperature is in the range of 500-900 °C and is carried out in a N_2 atmosphere. Since the chemical and possibly structural nature of boron nitride and titanium nitride are very similar, interdiffusion occurs, as is confirmed by Rutherford backscattering spectroscopy experiments. As a consequence of this diffusion, the titanium atoms replace some of the boron nitride atoms. However, titanium is generally tetravalent while boron is trivalent. This difference in electronic structure between titanium and boron is the primary mechanism by which the resistivity is systematically altered. The extra electron available in this alloyed layer provides a route for electronic transport to occur, thereby reducing the resistivity. Further systematic alterations can be made over either a smaller range of resistivity or a larger range through careful tuning of the amount of TiN that is alloyed into the boron nitride.

In yet another embodiment, coating material 2204 is prepared as a multilayer of TiN and BN rather than as a alloy of these two materials.

In still another embodiment, support structure 2202 is itself made up of ceramic boron nitride and the surface of this support structure 2202 is coated with a thin layer of titanium nitride, coating material 2204. This TiN layer is then annealed at elevated temperature to diffuse the TiN into the BN layer and therefore create a surface layer of lower resistivity. For example, the resistivity of the surface can be altered from the high bulk value of 10^{12} Ωcm to a lower value, depending on the thickness and annealing temperature of the TiN surface layer. Both the materials

used in this approach are available as low cost and in high purity. This approach is very easily manufacturable.

With reference next to Figure 23, another embodiment 2300 of the present
5 invention is shown. In the present embodiment, an underlying support structure 2302 has a coating material 2304 disposed thereon wherein the coating material is comprised of Nd_2O_3. Nd_2O_3 has a combination of properties that allow this material to be used as insulating components or surface coatings for reducing secondary electron emission in vacuum electronics applications. The maximum SEEC is 1.8.
10 The resistivity is greater than 5.0×10^{10} ohm-cm and remains very high under electron dose of 1 C/cm2 at 1.5 kV. Furthermore, the Nd_2O_3 coating material 2304 of the present embodiment has a low SEEC, single-valance at 1 atm and chemical stability (little reaction with moisture and no oxygen loss at 1100C in H2).

15 Referring now to Figure 24, another embodiment 2400 of the present invention is shown. The present embodiment expands coating materials from binary to ternary to improve performance in SEEC, resistivity and e-beam stability. More specifically, in the present embodiment, support structure 2402 has a coating material 2404 disposed thereon wherein the coating material is selected from the ternary systems
20 consisting of Cr_2O_3-Nd_2O_3, Nd_2O_3-MnO, and Cr_2O_3-MnO. The ternary oxides of the present embodiment allow us to exploit structural and alloying effects for reducing SEEC, to optimize resistivity, and to reduce hydrocarbon sticking to the support structure 2402.

25 Referring now to Figure 25, another embodiment 2500 of the present invention is shown. In the present embodiment, support structure 2502 has a coating material 2504 disposed thereon. In this embodiment, coating material 2504 is comprised of a

metal sulfide. More particularly, in one embodiment, coating material 2504 is comprised of a metal sulfide selected from the group consisting of MoS_2 and WS_2. Coating material 2504 of the present embodiment has SEEC as low as metals (delta max around 1). In this embodiment, metal sulfides are used as surface coatings for

5   reducing secondary electron emission in vacuum electronics. Furthermore, in one embodiment, the metal sulfide coatings are created by reacting oxide coatings with H_2S and H_2 mixtures.

With reference now to Figure 26, another embodiment 2600 of the present

10   invention is shown. In this embodiment, support structure 2602 has a double layer coating material 2604 disposed thereon. In this embodiment, a double layer coating is comprised of a first layer A and a second layer B, wherein A and B have different electron densities such as Cr_2O_3 and Nd_2O_3. By choosing properly the thickness of A and B, the present embodiment achieves a SEEC of a multilayer coating which is

15   lower than that of the individual coating, A or B. The multilayer coatings of the present embodiment are designed under several principles, for example, coating material 2604 of one embodiment is made with a structure similar to optical coatings for reducing light reflection from lens. Here, light reflected at the interfaces of the multilayer coatings interferes in a destructive manner. As a result, little light

20   (electrons) is reflected (emitted) from the lens (support structure 2602); (b) the multilayer coatings are made in such a way that they are more transparent to high-energy incident electrons than to low-energy secondary electrons. In this case, the coating behaves like a one-way glass, and the multiple interfaces with abrupt change in electron density can enhance the scattering of electrons leading to reduction in the

25   escape length of secondary electrons and a lower SEEC.

Referring still to Figure 26, in one embodiment, coating material 2604 is comprised of a double layer of Cr_2O_3 on Nd_2O_3. Cr_2O_3 is not sticky to hydrocarbon but is too conducting when the coating is thicker than 100A. On the other hand, Nd_2O_3 meets the resistivity requirement, but is too sticky to hydrocarbon and water.

5   Therefore, in the present embodiment, a thin layer of Cr_2O_3 (e.g. approximately 30 Angstroms) is coated onto a relatively thick Nd_2O_3 coating (e.g. approximately 100 Angstroms). As a result, the present embodiment, provides a coating that is more resistive, less sticky to hydrocarbons, and better moisture-resistant. Furthermore, the present embodiment, the total thickness of the double coating 2604 is sufficiently

10   high to achieve the full benefit of a charging-reduction coating.

As yet another advantage of the above-described embodiments, the spacer assemblies have good stability. That is, in addition to tailoring the secondary electron emission coefficient function to a value of near 1.0 along the entire length thereof, the

15   spacer assemblies do not degrade severely when subjected to electron bombardment. By not degrading, the spacer assemblies do not significantly contribute to contamination of the vacuum environment of the field emission display device. Additionally, the many of the materials comprising the various spacer assemblies of the above embodiments can easily have contaminant carbon removed or washed

20   therefrom prior to field emission display sealing processes. Also, many of the materials comprising the various spacer assemblies of the present embodiments do not deleteriously collect carbon after the field emission display seal process. As a result, many of the present embodiments are not subject to carbon-related contamination effects.

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Thus, the present invention provides a spacer assembly which is tailored to provide a secondary electron emission coefficient of approximately 1 for the spacer

assembly when the spacer assembly is subjected to flat panel display operating voltages. The present invention further provides a spacer assembly which accomplishes the above achievement and which does not degrade severely when subjected to electron bombardment. The present invention further provides a spacer

5 assembly which accomplishes both of the above-listed achievements and which does not significantly contribute to contamination of the vacuum environment of the flat panel display or be susceptible to contamination that may evolve within the tube.

The foregoing descriptions of specific embodiments of the present invention

10 have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others

15 skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.